# All-ceramic single crowns supported by zirconia implants: 5-year results of a prospective multicenter study

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Abstract: OBJECTIVES To assess survival/success rates and patient-reported outcome of zirconia-based posterior single crowns (SCs) supported by zirconia implants in a prospective two-center study after five years of observation. MATERIAL AND METHODS Forty-five patients were restored with 45 zirconia implant-supported posterior SCs composed of zirconia frameworks hand-layered with a leucite-reinforced feldspathic ceramic. Survival rates of SCs were assessed and technical success was evaluated according to modified United States Public Health Care (USPHS) criteria. Furthermore, patient-reported outcome measures (PROMs) were assessed by applying visual analog scales (VAS). Wilcoxon matched-pairs signed-rank test, mixed-effects ordered logistic regression, and linear mixed models were used to evaluate time effects on response variables. RESULTS Forty patients were available after a mean observation period of 61.0 ± 1.4 months. One SC had to be replaced, resulting in a Kaplan-Meier (KM) survival estimate for the SCs of 97.5 ± 2.47%. Since nine reconstructions showed at least in one category a major deviation from the ideal (five major chippings, four with increased occlusal roughness, one significant crevice, and one pronounced over-contouring), the KM success estimate was 79.3 ± 5.8%. Incidence of chipping (n = 19) and occlusal roughness (n = 35) was frequent ($p < 0.001$). All PROMs at prosthetic delivery except for speech ($p = 0.139$) showed significantly improved VAS scores (81%-94%; $p < 0.001$) compared to pre-treatment evaluations. Thereafter, no decrease in satisfaction could be observed until the 5-year follow-up (93%-97%). CONCLUSION Veneered zirconia-based SCs supported by zirconia implants showed high survival rates and highly satisfied patients' needs. However, significant incidence of technical complications is compromising the clinical long-term outcome for this indication.

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# All-ceramic single crowns supported by zirconia implants:

# 5-year results of a prospective multicenter study

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**Abstract**

*Objectives:* To assess survival/success rates and patient-reported outcome of zirconia-based posterior single crowns (SCs) supported by zirconia implants in a prospective two-center study after five years of observation.

*Material and Methods:* Forty-five patients were restored with 45 zirconia implant-supported posterior SCs composed of zirconia frameworks hand-layered with a leucite reinforced feldspathic ceramic. Survival rates of SCs were assessed and technical success was evaluated according to modified United States Public Health Care (USPHS) criteria. Furthermore, patient-reported outcome measures (PROMs) were assessed by applying visual analog scales (VAS). Wilcoxon matched-pairs signed-rank test, mixed-effects ordered logistic regression and linear mixed models were used to evaluate time effects on response variables.

*Results:* Forty patients were available after a mean observation period of 61.0±1.4 months. One SC had to be replaced, resulting in a Kaplan-Meier (KM) survival estimate for the SCs of 97.5±2.47%. Since 9 reconstructions showed at least in one category a major deviation from the ideal (5 major chippings, 4 with increased occlusal roughness, one significant crevice and one pronounced over-contouring), the KM success estimate was 79.3±5.8%. Incidence of chipping (n=19) and occlusal roughness (n=35) was frequent ($p<0.001$). All PROMs at prosthetic delivery except for speech ($p=0.139$) showed significantly improved VAS scores (81-94%; $p<0.001$) compared to pre-treatment evaluations. Thereafter, no decrease in satisfaction could be observed until the 5-year follow-up (93-97%).

*Conclusion:* Veneered zirconia-based SCs supported by zirconia implants showed high survival rates and highly satisfied patients' needs. However, significant incidence of technical complications is compromising the clinical long-term outcome for this indication.

German Clinical Trials Register (ID: DRKS00000226)

## Introduction

Ceramic implants were introduced to dentistry half a century ago, at about the same time with their counterpart made from titanium. In these days, aluminum oxide was used for manufacturing the first market-available ceramic implants like the “crystalline bone screw” or the “Tübingen immediate implant” (Sandhaus, 1967; Schulte & Heimke, 1976). However, reports addressing the clinical outcome of these products are sparse. Due to its reduced fracture toughness, technical failures of dental implants made from aluminum oxide were frequent. This resulted in concerns of most practitioners and implants made from aluminum oxide are no more available on the market. Meanwhile, titanium became the gold-standard material for implant manufacturing and titanium implant supported reconstructions cover the full range of clinical indications from partial to complete fixed and removable dental prostheses (R. E. Jung, Zembic, Pjetursson, Zwahlen, & Thoma, 2012; Kern, Kern, Wolfart, & Heussen, 2016; Pjetursson, Thoma, Jung, Zwahlen, & Zembic, 2012). On the contrary, ceramic dental implants might still be considered a niche product. Along with the introduction of stabilized zirconium dioxide as promising implant bulk material and a rising discussion on whether the reported prevalence of inflammation in tissues surrounding titanium implants might partially associated with titanium particles resulting from tribocorrosion (Fretwurst, Nelson, Tarnow, Wang, & Giannobile, 2018), interest in zirconia dental implants markedly increased within the last decade.

In the first instance, research focused on the osseointegration capacity of one-piece zirconia implants in animal investigations (Pieralli, Kohal, Lopez Hernandez, Doerken, & Spies, 2018) and, later on, in clinical trials (Pieralli, Kohal, Jung, Vach, & Spies, 2017). Whereas osseointegration of zirconia implants was shown to be similar to titanium implants, reduced susceptibility to peri-implant inflammatory processes still needs to be scientifically

evidenced. Now that osseointegration seems to be sufficiently proven, research interest more and more focusses on how to restore zirconia one-piece implants requiring cementation of the prostheses. Besides laboratory studies evaluating cementation techniques (Zaugg, Meyer, Rohr, Zehnder, & Zitzmann, 2018; Zaugg, Zehnder, Rohr, Fischer, & Zitzmann, 2018), there are few data available reporting on the clinical performance of all-ceramic single crowns and three-unit fixed dental prostheses supported by zirconia implants (Spies, Stampf, & Kohal, 2015). It seems that zirconia based bi-layered reconstructions reveal the same technical complication range known from the restoration on titanium implants: whereas the zirconia framework is not prone to failure, but the veneering ceramic appears to be the weakest link, suffering from chip-off fractures and roughening of the surface.

In an earlier report, it was shown that zirconia implant supported single crowns in posterior regions entirely survived a three-year observation period (Spies, Balmer, et al., 2017). However, incidence of minor chippings and occlusal roughness was highly significant. Interestingly, these minor technical complications had no impact on the highly satisfied patient-reported outcome. It was finally concluded, that patient satisfaction and restoration survival might decrease over the course of the follow-up appointments in case of further progress, potentially resulting in the need for replacements in the future. Therefore, the aim of the present report was to assess the ongoing technical and patient-reported outcomes from the three- to five-year follow-up.

## Materials and Methods

*Study design*

This prospective multicenter study was performed in two centers located in Switzerland (Center of Dental Medicine, University of Zürich, Clinic of Fixed and Removable Prosthodontics and Dental Material Science) and Germany (Medical Center, University of Freiburg, Department of Prosthetic Dentistry). The study protocol was approved by both local responsible ethics committees (Freiburg: 241/08; Zürich: StV 08/10). The study was registered in the German Clinical Trials Register (ID: DRKS00000226) and is listed in the WHO International Clinical Trials Registry Platform. All included patients gave informed consent prior to their inclusion (04/2010-07/2012). This prospective cohort study was designed and performed considering the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement for cohort studies (http://www.strobe-statement.org) and therefore in compliance with the appropriate EQUATOR guidelines.

*Participants*

Sixty patients with one or three adjacent missing teeth were recruited. They needed to be compliant, aged between 20 and 70 years, show a good health status, have sufficient bone volume in the area destined for implant installation, show a stable occlusal relationship, and no signs of pronounced bruxism (such as attrition, pain on muscular palpation, pain-causing joint sound, or self-reported clenching habits). Reasons for exclusion were smoking (>10 cigarettes per day), alcohol or drug abuse, known destructive habits, and health conditions not permitting the surgical procedure.

The procedure of implant installation and assessments of the clinical outcome have been described earlier (Balmer et al., 2018; Ronald E. Jung et al., 2016). In brief: Late implant placement by raising a mucoperiostal flap was followed by transmucosal healing. If required,

guided bone regeneration was performed with a bovine bone substitute and a porcine collagen membrane. The supporting one-piece zirconia implants (ceramic.implant; vitaclinical, VITA Zahnfabrik, Bad Säckingen, Germany) were composed of 3 mol% yttria stabilized tetragonal zirconia polycrystals (3Y-TZP: $ZrO_2$ 93%, $Y_2O_3$ 5%, $HfO_2$ 1.9%, $Al_2O_3$ 0.1% [% w/w]) and provided in diameters of 4.0, 4.5, and 5.5 mm. In total, 49 implants were installed to support 49 SCs (Spies, Balmer, et al., 2017). In the eleven remaining patients three-unit bridges were supported by two implants. To obtain a clear indication for the present evaluation of posterior single crowns, three patients with three anterior crowns and the eleven patients restored with three-unit bridges were excluded from the analysis.

*Clinical and laboratory procedures*

Detailed information on the clinical and laboratory procedures was given in precedent publications reporting mid-term results after 36 months of observation (Balmer et al., 2018; Spies, Balmer, et al., 2017). In brief, implants were immediately temporized with prefabricated provisional reconstructions. After a minimum healing period of eight (lower jaw) or 16 weeks (upper jaw), respectively, impressions were taken with a polyether material (Impregum; 3M Espe, Seefeld, Germany) and digitized in the dental laboratory (inEos scanner; Sirona, Bensheim, Germany). Zirconia frameworks (In-Ceram YZ, VITA Zahnfabrik; 3Y-TZP: $ZrO_2$ 94.9%, $Y_2O_3$ 5%, $Al_2O_3$ 0.1% [% w/w]) were CAD/CAM-fabricated (Cerec inLab® software, inLab® MC XL 4-axis milling device; Sirona) and finally hand-layered with a leucite-reinforced feldspathic ceramic (VM9, VITA Zahnfabrik) according to the manufacturer's instructions. Final SCs were adhesively cemented using a dual-curing resin cement (RelyX Unicem Aplicap; 3M Espe). If a subgingival restoration margin was present, retraction cords were placed to facilitate removal of cement remnants. Centric and dynamic occlusions were controlled and adjusted by reducing premature contacts, if present, to protect the SCs from any excessive forces. In all patients, anterior

and/or canine guidance was verified with immediate posterior disclusion of replaced molars and premolars when making lateral or protrusive movements. In each center, one master dental technician was responsible for the manufacturing of all reconstructions.

*Baseline and follow-up examinations*

At baseline, after final reconstruction cementation and again after 6, 12, 24, 36 and 60 months of function, the patients were scheduled for clinical examination. Examinations consisted of a visual and tactile inspection of the SCs, a control of static and dynamic occlusal contacts, impression taking, and intraoral photographs of the SCs and adjacent teeth. Biological and technical complications were recorded. A required treatment was applied, if necessary.

*Technical examination*

Technical aspects were clinically evaluated according to modified USPHS (United States Public Health Service) criteria. In brief, the reconstructions were examined for fracture of framework or of the veneering ceramic, occlusal roughness, marginal integrity and under/ overcontouring. All parameters were rated “Alpha” in case of no problem, “Bravo” in case of minor extent of the complication, “Charlie” if the complication was major, and “Delta” if the reconstruction had to be replaced due to the complication (Tab. 1). In both centers, one single examiner was responsible for the technical exams. Examiners were trained and continually calibrated by visualization of the above mentioned parameters and possible ratings in xemplary clinical photographs.

*Patient-reported outcome*

The patients` appraisal of function, esthetics and appearance, sense, speech, and self-esteem relating to the inserted reconstructions were assessed. At study inclusion, final prosthesis insertion, and at every follow-up appointment, all included subjects labeled a point on a line

that corresponded with their personal satisfaction in the aforementioned categories (Visual analog scales; VAS). The line was 100 mm in length and showed no scale. Every millimeter of the line corresponded to 1% of satisfaction (from 0% at the left end of the line to 100% at the right end of the line).

*Statistical analyses*

Sample size calculation was performed considering the radiographic outcome (expected marginal bone loss known from the literature) and was, therefore, not primarily designed for the evaluation of the prosthetic outcome (13). Means, medians, and standard deviations were computed for descriptive analyses of the data. KM survival and success estimates were calculated and graphically presented using plots. Moreover, log-rank tests were used to check for an influence of co-variables (gender, jaw, and center). A Wilcoxon matched-pairs signed-rank test was used to calculate for changes between prosthetic delivery and the 60 month-follow-up (USPHS criteria, PROMs). A mixed-effects ordered logistic regression (USPHS) and a linear mixed model (PROMs) were used to analyze a linear time trend including the data from all measurements (Delivery, 6m, 12m, 24m, 36m, 48m, 60m).

All calculations were performed with the STATA 14.2 (StataCorp LT, College Station, TX, USA) statistical software. The probability level for statistical significance was set to $p < 0.05$.

## Results

*Status of follow-up*

Since one patient lost his implant during the healing period (considered as drop-out for the evaluation of final single crowns), 45 out of initially 46 patients provided with 45 posterior SCs remained for evaluation (Tab. 2). Details regarding the opposing dentition can be found in Table 3. Final restoration delivery took place in between 04/2010 and 02/2012. Mean age

of patients was 46.6 ± 13.1 years (range: 25–69 years) at this time point. Of the 45 included patients, 40 patients with 40 SCs were seen at the final follow-up in between 05/2015 and 07/2017 (Fig. 1), resulting in a mean observation time of 61.0 ± 1.4 months. Five patients refused further participation in the study in between restoration delivery (one patient refused further participation after final prosthetic delivery without giving a reason and was considered as drop-out for analyses) and the four-year follow-up (likewise giving no reason for study withdrawal). For the current analyses, these four patients/SCs were considered drop-outs.

*Clinical outcome*

One SC had to be replaced due to a severe chipping of the veneering ceramic (rated "Delta"), resulting in a KM survival estimate of 97.5 ± 2.47% (CI: 83.55 – 99.64; Fig. 2). Since 9 reconstructions showed at least in one category a major deviation from the ideal (rated "Charlie": 5 major chippings, 4 with increased occlusal roughness, one significant crevice and one pronounced over-contouring), the KM success estimate was 79.3 ± 5.8% (Fig. 3a, Tab. 4). Compared to baseline, incidence of chipping (n=19) and occlusal roughness (n=35) was significant ($p<0.001$). Compared to the three-year follow-up, five more SCs were affected by chipping and eight more SCs by occlusal roughening. Due to chip-off fractures, contour of reconstructions changed over time ($p<0.009$). The KM estimate for a SC not to be affected by any chipping at the end of the five-year follow-up was 51.6 ± 5.8% (Fig. 4). No change in marginal disintegration compared to the last report after three years of observation was found. No framework fracture or loss of retention was observed. Performed log-rank tests revealed no statistically significant differences for the success curves regarding jaw ($p = 0.681$; maxilla: 82.6 ± 9.1%, mandible: 76.9 ± 9.1%; Fig. 3b) and sex ($p = 0.858$; females: 81.0 ± 10.0%, males: 78.4 ± 8.6%; Fig. 3c). However, the center showed to have significant influence on the success rate ($p = 0.048$; center 1: 94.7 ± 5.1%, center 2: 67.0 ± 10.2%; Fig.

3d). Regarding the absence of any type of chipping (major and minor), log-rank tests revealed no difference regarding jaw (p = 0.855; maxilla: 50.7 ± 12.5%, mandible: 52.4 ± 10.0%), sex (p = 0.370; females: 42.3 ± 12.0%, males: 58.3 ± 10.0%), and center (p = 0.204; center 1: 66.7 ± 11.1%, center 2: 39.7 ± 10.2%).

*Patient-reported outcome (VAS)*

Compared with baseline values prior to treatment (67-93%, sense was not assessed prior to implant installation; Fig. 5, Tab. 5), all PROMs at prosthetic delivery except for speech (p=0.139) showed significantly improved VAS scores (81-94%; p<0.001). Thereafter, no decrease in satisfaction could be observed over time until the 5-year follow-up (93-97%). Chipping incidence did not affect patient satisfaction (p≥0.140).

## Discussion

The present multicenter cohort investigation revealed excellent survival of the evaluated, zirconia implant supported, bi-layered crowns composed of a zirconia framework hand-layered with a leucite reinforced veneering ceramic. Moreover, patients were highly satisfied with the treatment during the entire observation period of 61 months. However, a significant incidence of technical complications (chipping and occlusal roughness) was observed. Five major chippings, 4 crowns with increased occlusal roughening, one significant marginal opening and one pronounced over-contouring resulted in a reduced KM success estimate. Including minor deviations from the ideal (e.g. minor chippings or small area roughness to be polished intraorally), occurrence of such events was found to be highly statistically significant. Almost half of the SCs were affected by fractures of the veneering ceramic. Therefore, the initially raised hypothesis that ongoing technical complications after the three-

year follow-up might result in replacements and dissatisfied patients has to be rejected (only one replacement and highly satisfied patients were determined).

A recent systematic review and meta-analysis screening the nowadays available literature on implant-supported all-ceramic single crowns showed, that veneered zirconia-based reconstructions can still be considered the biggest stakeholder for all-ceramic implant-supported replacement of single missing teeth (Rabel, Spies, Pieralli, Vach, & Kohal, 2018). After five years of observation, the meta-analysis revealed a survival estimate of 92.0% for zirconia-based bi-layers, ranging from 67.4 (Bömicke, Gabbert, Koob, Krisam, & Rammelsberg, 2017) to 100% (Hosseini, Worsaae, Schiodt, & Gotfredsen, 2011; Lops, Bressan, Chiapasco, Rossi, & Romeo, 2013; Wittneben et al., 2017). This indicated that the survival of the present single crowns is above average. On the contrary, in the mentioned review, the estimated occurrence of veneer fractures after five years of observation was calculated to be 11.3% (Rabel et al., 2018), which is high but considerably lower compared to the outcome of the present investigation. Included studies mostly applied the hand-layering technique for veneering zirconia frameworks. Interestingly, chipping was quite a heterogeneous outcome among included studies ranging from 0% after 12 months of observation (Hosseini et al., 2011) up to 45.9% after 3 years of observation (Bömicke et al., 2017). This might indicate a high technique sensitivity of different veneering procedures and applied materials. In the present investigation, the KM estimate for chipping events was 48.4% after 5 years. As a result, the chipping frequency in the present study was significantly higher than the estimate calculated by Rabel and collaborates (Rabel et al., 2018). One reason for this might be considered the fact, that reconstructions of the present evaluation were located in posterior regions, whereas multiple investigations in the meta-analyses included a mixture of both anterior and posterior reconstructions (Chappuis et al., 2018; Nejatidanesh, Moradpoor, & Savabi, 2016; Paolantoni, Marenzi, Blasi, Mignogna, & Sammartino, 2016;

Tartaglia, Sidoti, & Sforza, 2015; Wittneben et al., 2017; Worni, Kolgeci, Rentsch-Kollar, Katsoulis, & Mericske-Stern, 2015). It was shown, that single crown location has a significant impact on the occurrence of veneer fractures in favor of reconstructions located in the anterior region (Rabel et al., 2018). Nevertheless, since nearly half of the reconstructions of the present evaluation were affected by minor fractures of the veneering ceramic, the concept of bi-layered zirconia-based reconstructions for the replacement of premolars and molars might be questioned. Since all reconstructions of the present investigation were supported by one-piece ceramic implants, cementation of the crowns was mandatory. Screw-retention, however, would facilitate laboratory maintenance or replacements in case of severe technical complications or failure. Since evidence for two-piece ceramic is nowadays still sparse, research should address this treatment option in the future.

A significant change in reconstruction contour over time that was found in the present work might be considered a result of the high incidence of chip-off fractures requiring re-polishing, thereby compromising the original shape of the crowns. Considering susceptibility for fracture events, monolithic reconstructions made from lithium disilicate showed to be less prone for this technical complication (Spies, Pieralli, Vach, & Kohal, 2017). However, data for the monolithic type of reconstructions supported by implants is still rare (Rabel et al., 2018).

Occlusal roughness was another technical outcome that was assessed in this investigation. At the final follow-up appointment, all - except 5 reconstructions - were categorized to show at least a slight roughness of the occlusal surface. Occurrence of this event was calculated to be highly significant over time ($p<0.001$). Regrettably, data on roughening of veneering ceramics is only seldom provided in the literature and was, therefore, not included as outcome in the above mentioned review (Rabel et al., 2018). Several reasons can be assumed for increased roughness of veneering ceramics including a crystalline phase over time in the

oral cavity like tooth brushing (Garza, Thompson, Cho, & Berzins, 2016), environmental conditions (Vechiato-Filho et al., 2015), abrasion due to mastication (Lawson, Bansal, & Burgess, 2016) or attrition due to antagonistic wear (Amer, Kürklü, & Johnston, 2015). All mentioned conditions can result in dissolution of the amorphous phase while crystalline parts of the lattice remain at the restorations surface acting as potential abrasives. In the present investigation, roughened surfaces were re-polished at every follow-up appointment. However, it could be shown that intraoral polishing might not be capable to recreate the same smooth surface finish as received from the dental laboratory after final firing (Vrochari et al., 2015). Irrespective of the exact etiology (reasons might be multifactorial), surface roughness is considered to be strongly related with bacterial adherence (Vo et al., 2015) and fracture resistance (Albakry, Guazzato, & Vincent Swain, 2004; Rashid, 2014). It was already shown, that surface roughening of veneering ceramics can be considered as a precursor for upcoming fracture (Spies, Witkowski, Vach, & Kohal, 2018). Therefore, the results of the present investigation suggest a need for recall-sessions on a regular basis.

In the present evaluation, the center (Zurich/Freiburg) showed to have a significant influence on the success rate of the reconstructions. Technical procedures during fabrication of the crowns or the examiners might have affect this outcome. While both master dental technicians followed the manufacturers processing information to the extent possible, potential failure might be more likely identified in an examiner calibration in between both centers capable of improvement. A web-based training and calibration tool might help to overcome this potential source of error in future clinical research. Particularly, differentiation of “Bravo” and “Charlie” ratings is prone to misinterpretation and, therefore, liable in accidentally falsifying success rates of different centers.

Finally, it needs to be mentioned that a missing control group (e.g., monolithic reconstructions made from lithium disilicate, hybrid ceramics or a new generation of highly translucent zirconia) represents a major limitation of the present study. Therefore, one cannot conclude that the presented findings show superiority or inferiority over monolithic treatment protocols for restoring zirconia dental implants. Apparently, the patients were not aware of the technical complications with the crowns. The highly positive patient-centered outcome might have several other reasons than participants favoring the applied ceramic materials like, exemplary, simply giving the patients missing posterior support. In future projects, a more detailed and validated patient satisfaction questionnaire, like the one suggested and modified by Walton and Layton, exploring patient-centered outcomes more comprehensively might further improve the understanding of patient's awareness over the years of follow-up (Layton & Walton, 2011; Walton & Layton, 2017). Besides determining levels of satisfaction with the appearance of the reconstruction, appearance of the soft tissues, cleansibility, cost and overall satisfaction with the treatment by means of a VAS, the suggested questionnaire asks whether the participant would elect to undergo the treatment again if required or would recommend the treatment to a friend.**Conclusions**

Survival of the posterior zirconia-based SCs supported by zirconia oral implants was excellent. However, the success rates were negatively influenced by high technical complication rates. After five years of observation, these complications still had no significant impact on patients' satisfaction. Nevertheless, monolithic approaches might be preferable to overcome this issue but there is a lack of scientific data. In further clinical research, it is recommended to evaluate monolithic SCs for a time- and cost-effective restoration of one-piece zirconia oral implants installed in posterior areas.

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**Figure legends**

Fig. 1: Representative reconstructions at the five-year follow-up appointment (a: non-successful SC due to increased occlusal roughening; b: successful SC showing a small-area roughness on the disto-lingual cusp; c: successful SC showing a minor chipping on the distal aspect of the occlusal surface; d: successful SC not showing any deviation from the ideal).

Fig. 2: Kaplan-Meier survival plot.

Fig. 3: Kaplan-Meier success plots (a: overall; b–d: stratified by jaw, sex, and center).

Fig. 4: Kaplan-Meier success plot considering minor chippings as non-success.

Fig. 5: Visualization of patient-reported outcome measures (VAS score [%]) at pre-treatment, final delivery of the prosthetic restoration and the follow-up appointments up to five years including statistical evaluations.

Tab. 1: Modified USPHS criteria for the success and survival analyses of the restorations

| | **Alpha (A)** | **Bravo (B)** | **Charlie (C)** | **Delta (D)** |
|---|---|---|---|---|
| **Fracture of framework** | No fracture | - | - | Fracture (Loss of reconstruction) |
| **Fracture of veneering ceramic** | No fracture | Minor chipping (polishable) | Major chipping (up to framework) | Fracture (Loss of reconstruction) |
| **Occlusal roughness** | No roughness | Slight roughness (Ø < 2 mm) | Obvious roughness (Ø > 2 mm) | Reconstruction needs to be replaced |
| **Marginal integrity** | No visible or soundable gap | Marginal gap slightly soundable | Explorer penetrates a significant crevice | Reconstruction needs to be replaced |
| **Contour of reconstruction** | Perfectly contoured | Slightly under- / overcontoured | Pronounced under- / overcontouring | Reconstruction inacceptable |
| | **Success** | | **Survival** | **Failure** |

Tab. 2: Distribution of the 44 implant-supported posterior single crowns

| **Jaw** | | **Sex** | | **Center** | | **Region** | |
|---|---|---|---|---|---|---|---|
| Maxilla | Mandible | Female | Male | Freiburg | Zurich | Premolar | Molar |
| 18 | 26 | 19 | 25 | 19 | 25 | 17 | 27 |

Tab. 3: Surface composition of the opposing dentition (two antagonists)

| | *n* |
|---|---|
| Natural teeth | 29 |
| At least one antagonist with a SC | 9 |
| Tooth-supported fixed dental prosthesis | 3 |
| Implant-supported fixed dental prosthesis | 2 |
| Tooth-retained removable dental prosthesis | 1 |

Tab. 4: Results of the single crown evaluations according to the modified USPHS criteria (Tab. 1) at prosthetic delivery and the follow-ups. Four patients refused further participation in the study in between the one- and four-year follow-up. Significance (Wilcoxon matched-pairs signed-rank test[1]) was calculated for changes between delivery and the 60m follow-up. Furthermore, mixed-effects ordered logistic regression[2] was used to analyze a linear time trend including the data from all measurements (Delivery, 6m, 12m, 24m, 36m, 48m, 60m).

| | **Framework fracture** | **Chipping of veneering** | **Occlusal roughness** | **Marginal integrity** | **Contour** |
|---|---|---|---|---|---|
| | *n* (Alpha / Bravo / Charlie / Delta) | | | | |
| **Delivery** | *44* (44/-/-/-) | *44* (43/1/-/-) | *44* (31/13/-/-) | *44* (42/1/1/-) | *44* (19/24/1/-) |
| **6m Follow-up** | *44* (44/-/-/-) | *44* (39/4/1/-) | *44* (22/21/1/-) | *44* (41/2/1/-) | *44* (23/20/1/-) |
| **12m Follow-up** | *44* (44/-/-/-) | *44* (36/7/1/-) | *44* (18/26/-/-) | *44* (40/3/1/-) | *44* (19/24/1/-) |
| **24m Follow-up** | *42* (42/-/-/-) | *42* (33/8/1/-) | *42* (14/28/-/-) | *42* (38/3/1/-) | *42* (17/24/1/-) |
| **36m Follow-up** | *40* (40/-/-/-) | *40* (26/12/2/-) | *40* (13/27/-/-) | *40* (33/6/1/-) | *40* (18/21/1/-) |
| **48m Follow-up** | *40* (40/-/-/-) | *40* (23/14/3/-) | *40* (12/26/2/-) | *40* (34/5/1/-) | *40* (16/24/0/-) |
| **60m Follow-up** | *40* (40/-/-/-) | *40* (21/13/5/1) | *40* (5/31/4/-) | *40* (33/6/1/-) | *40* (8/31/1/-) |
| **Significance[1]** | - | *<0.001* | *<0.001* | *0.025* | *0.025* |
| **Significance[2]** | - | *<0.001* | *<0.001* | *0.001* | *0.003* |

Tab. 5: Patient assessments of function (eating), esthetics and appearance, sense ("feeling like my own teeth"), speech and self-esteem (VAS, [%]) before treatment (P), at the delivery of the final restoration (D) and the follow-up appointments (1y, 3y, 5y). Four patients refused further participation in the study in between the one- and four-year follow-up. One file with PROM data was not recorded at the 3y follow-up. Significance (Wilcoxon matched-pairs signed-rank test) was calculated for changes between P and D (except for sense). Moreover, linear mixed models were used to calculate a linear time trend from D to 5y (D/1y/3y/5y in relation to the baseline value P) to verify a lasting effect.

| | | **Pre-Treatment (P)** | **Delivery (D)** | **1y Follow-up (1y)** | **3y Follow-up (3y)** | **5y Follow-up (5y)** | **Significance (p)** | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | P→D | D→5y |
| **Function (eating)** | *n* | *44* | *44* | *44* | *39* | *40* | **<0.001** | **0.006** |
| | **median VAS [%]** | **80** | **90** | **98.5** | **94** | **97** | | |
| | **mean VAS [%]** | **69.2** | **87.5** | **91.4** | **86.7** | **95.1** | | |
| | SD | 25.5 | 13.5 | 13.7 | 16.7 | 5.5 | | |
| **Esthetic / Appearance** | *n* | *44* | *44* | *44* | *39* | *40* | **<0.001** | 0.220 |
| | **median VAS [%]** | **81** | **94.5** | **97** | **95** | **97** | | |
| | **mean VAS [%]** | **66.5** | **88.7** | **89.2** | **85.4** | **92.7** | | |
| | SD | 30.6 | 13.3 | 18.2 | 19.5 | 16.6 | | |
| **Sense** | *n* | - | *44* | *44* | *39* | *40* | **-** | **0.014** |
| | **median VAS [%]** | **-** | **89.5** | **96** | **94** | **97** | | |
| | **mean VAS [%]** | **-** | **81** | **90.9** | **87.9** | **93.8** | | |
| | SD | - | 24.3 | 11.6 | 13.0 | 9.4 | | |
| **Speech** | *n* | *44* | *44* | *44* | *39* | *40* | 0.139 | 0.087 |
| | **median VAS [%]** | **98** | **98** | **98.5** | **97** | **98** | | |
| | **mean VAS [%]** | **92.8** | **93.6** | **94.6** | **92.7** | **97.0** | | |
| | SD | 11.0 | 13.5 | 9.4 | 9.3 | 3.7 | | |
| **Self-esteem** | *n* | *44* | *44* | *44* | *39* | *40* | **<0.001** | **0.020** |
| | **median VAS [%]** | **90.5** | **97** | **98** | **97** | **98** | | |
| | **mean VAS [%]** | **76.0** | **91.6** | **94.2** | **90.9** | **97.0** | | |
| | SD | 27.4 | 11.8 | 9.9 | 12.1 | 3.7 | | |